REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
1993

2. REPORT TYPE
Technical Paper

3. DATES COVERED *(From - To)*
See Attached List

4. TITLE AND SUBTITLE
See Attached List

5a. CONTRACT NUMBER
N/A

5b. GRANT NUMBER
N/A

5c. PROGRAM ELEMENT NUMBER
N/A

6. AUTHOR(S)
See Attached List

5d. PROJECT NUMBER
N/A

5e. TASK NUMBER
N/A

5f. WORK UNIT NUMBER
N/A

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
See Attached List

8. PERFORMING ORGANIZATION REPORT NUMBER
N/A

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
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10. SPONSOR/MONITOR'S ACRONYM(S)
N/A

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
N/A

12. DISTRIBUTION / AVAILABILITY STATEMENT

Distribution Statement A: Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
N/A

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF: UNCLASSIFIED			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE	Unlimited Distribution	See Attached List	Kristi Laug
					19b. TELEPHONE NUMBER *(include area code)* 937-255-3362

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CONCEPTUAL DESIGN STUDY OF A SOLAR CONCENTRATOR/

SUPPORT STRUCTURE: A THREE DIMENSIONAL FINITE ELEMENT MODEL

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ABSTRACT

Under the space environment the paraboloid solar concentrators and support structures can deform and hence the focal point of the concentrators can diffuse. If this diffusion is large, energy will not concentrate on the thruster as desired. This paper addresses this aspect of pointing and accuracy analysis of solar concentrators, due to equivalent thrust loads.

The previous studies were limited to the concentrator system being modeled with a simplified finite element model that includes only the support struts and torus. The torus model was made up of several equal length beams. The simple model did not contain the paraboloid reflector, and assumes the reflector does not affect the deformation of the torus. In the present study the inflated parabolic reflector is included in the model. The results demonstrate the non uniform displacements on the reflector that confirms the reflector's potato chipping effect.

INTRODUCTION

The Solar Propulsion Concept (SPC), consists of concentrators, solar energy absorbing thruster, and a single fuel tank. The SPC has the advantage of doubling specific impulse and hence doubling payload. This system can make Low Earth Orbit (LEO) to Geosynchronous Equatorial Orbit (GEO) missions less expensive. A light weight paraboloid concentrator and a support structure are needed for the Solar Propulsion Concept(1). Studies have shown that inflatable paraboloids offer great savings in payload and packaged volume compared to paraboloids mechanically erected in space (2,3). The reflectors and support structure should be packageable within the launch vehicle and must be deployable once Low Earth Orbit is achieved. Leakage through holes caused by meteoroids is easily compensated by make up gas, due to a very low pressure requirement. Other advantages of the inflatable models are improved dynamic performance through

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2. M. Thomas and G. J. Friese, " Pressurized Antennas for Space Radars," AIAA Collection CP 807, from the AIAA Sensor Systems for the 80's Conference, December 1980.
3. G. J. Friese, G. D. Bilyeu, and M. Thomas," Initial 80's Development of Inflated Antennas," L'Garde Report LTR-82 -GF-107, NASA Contractors Report, December 1982.

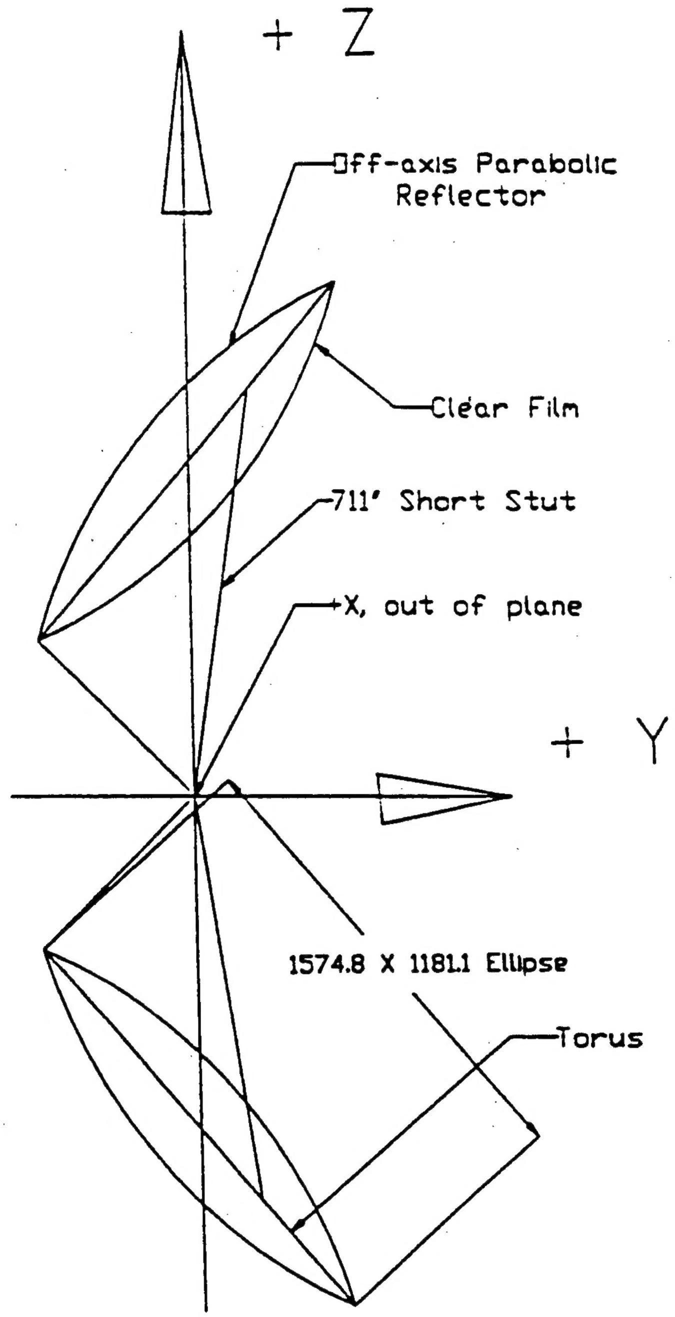

Figure 1: Solar Concentrator System

compensated by make up gas, due to a very low pressure requirement. Other advantages of the inflatable models are improved dynamic performance through rapid damping, non linear restoring forces, and reduction of thermal gradients (4).

Work on inflatable reflectors has been done for over 25 years. Paraboloids have been built and tested for surface accuracy and microwave performance (4). For solar concentrators, slope error is the key accuracy parameter for measuring gross surface distortion in construction. This has been addressed by M. Thomas (5).

Another aspect of accuracy of solar concentrators under the space environment is the concentrator deflection and rotation due to thrust and temperature. The reflector deflection and rotation tends to make the focal point too diffuse. If the diffusion of the focal point is large, energy will not concentrate on the thruster as desired. This paper addresses this aspect of pointing and accuracy of focal point diffusion in concentrators.
Purasinghe (6) and Ritchie (7) used two off axis paraboloid reflectors supported on a rigidized elliptical torus to study this problem. Each torus was supported on three struts which are fixed to a turntable [Figure 1]. It is assumed that the paraboloid reflectors were attached to the torus in such a way that reflectors do not affect the torus. This system was analyzed for equivalent thrust loads in space. The deflection results from this analysis at the focal point shows diffusion at the focal point. In the current study paraboloid mirror is included to study the effect of torus/mirror interaction.

METHODOLOGY

The finite element method was used with the MSC NASTRAN (8) Program. Two views of the finite element model of the support structure are shown in Figures 2 and 3. They consists of beam elements (CBAR) for both struts and torus. The torus was modelled with straight beam elements. The struts are fixed to the turntable. The reflector component consists of a reflective membrane and a geometrically identical transparent canopy. The two form together an inflatable lens like structure which under inflation, assumes a paraboloid shape. These were modelled with CQUAD4 shell elements of NASTRAN. The inflatable structure is supported along its rim by a bending resistant torus which was described earlier. The geometry and the material properties of the system are documented in Table 1.

The focal point displacement with reference to displacement and rotation of the torus was calculated with completely a new model with only three bars

4. A. J. Wendt and L. D. Surber, " Inflatable Antennas," 3rd Aerospace Expandable and Modular Structures Conference, AFAPL TR 68-17, Mar 67.
5. M. Thomas and G. Veal, " Scaling Characteristics of Inflatable Paraboloid Concentrators," Solar engineering, ASME 1991.
6) R. Purasinghe, " Pointing and Accuracy Analysis of Solar concentrators," ASME Solar Energy conference, DC, April 93.
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8) NASTRAN MANUAL, NASTRAN Finite Element Software.

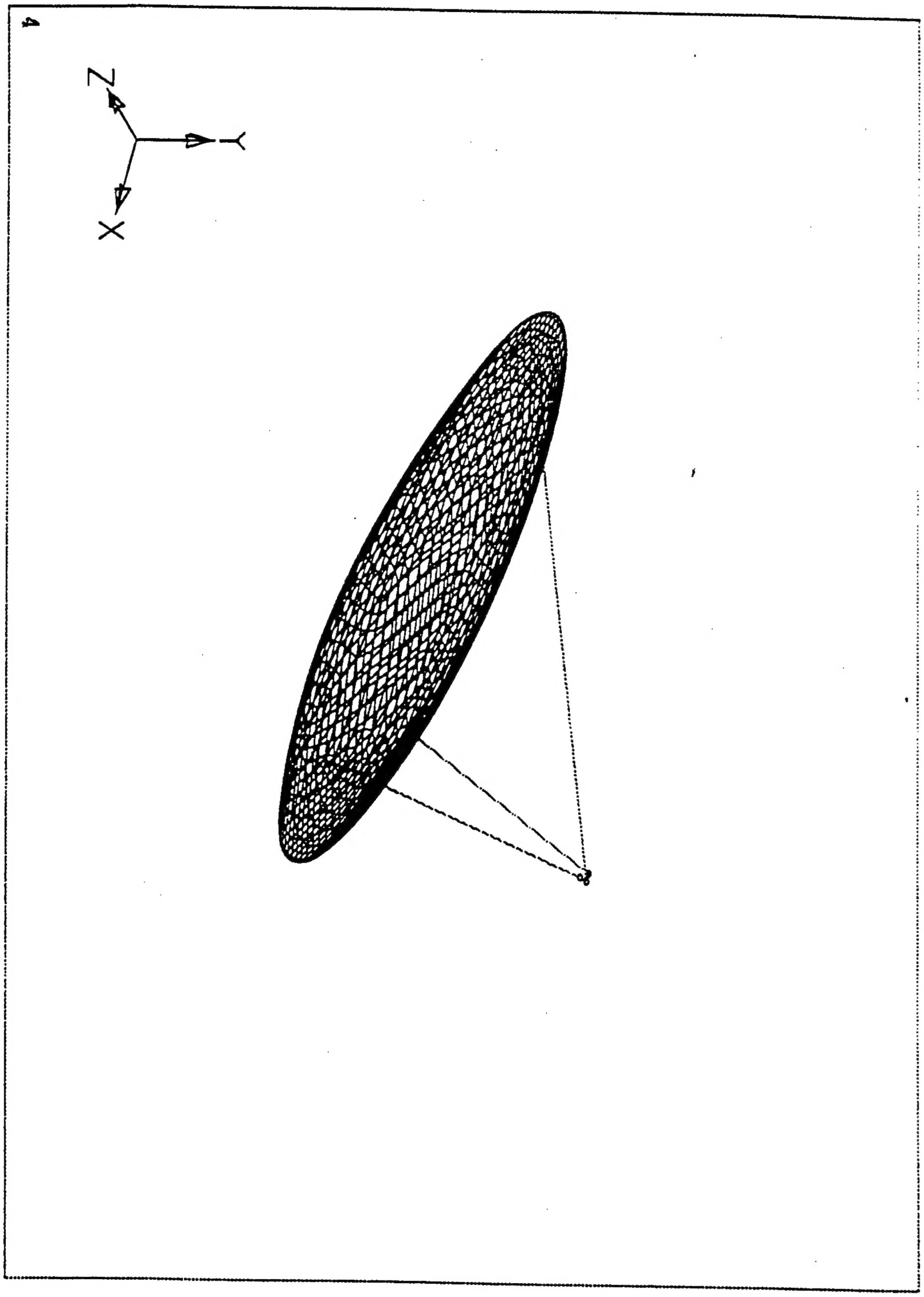

Figure 2: Nastran Finite Element

Model - View 1

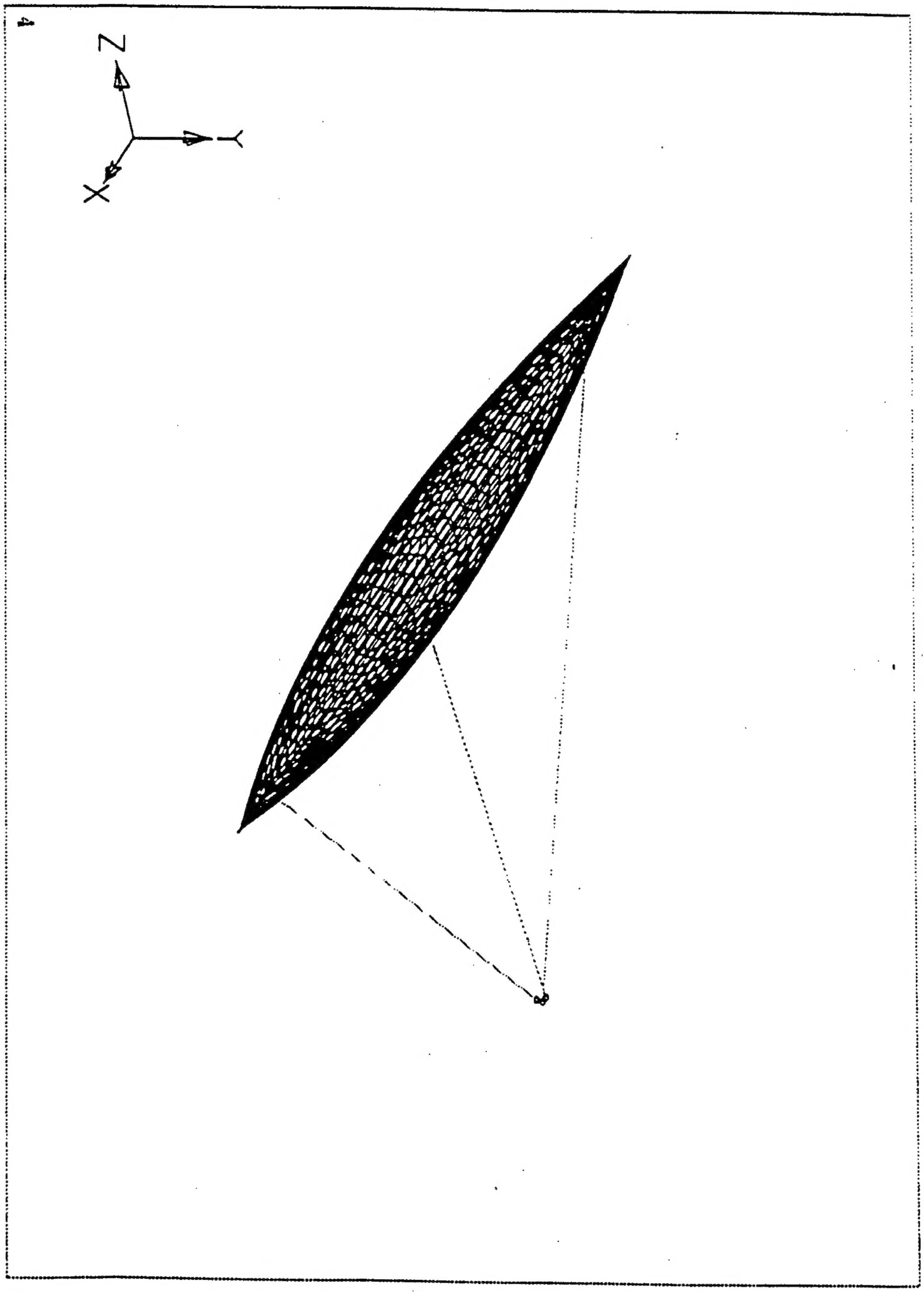

Figure 3: Nastran Finite Element

Model - View 2

with displacements and twice displacements enforced at one end of each bar. The displacements at the other end are the displacements of the focal point with reference to these points on the torus.

Table 1: Geometry and Material Properties

Nodal Coordinates of Strut 1	(0.0,-12.0,18) to (0.0 -520.8,514.2) inches
Nodal Coordinates of Strut 2	(10.39,6.0,18.0) to (540.96,208.9,1341.7) inches
Nodal Coordinates of Strut 3	(-10.39,6.0,18.0) to (-540.96,208.9,1341.7) inches
Center of Torus	(0.0,0.0,1104.8) inches
Focal Point of Paraboloid Mirror	(0.0,0.0,12.0) inches
Materials Used	Space Cured Gr/Ep composite with M40J fibers $\pm 30/0/90$ / 30 unidirectional tape
Density	0.059 lb/in^3 density
Modulus of Elasticity	17,210 ksi
Diameter of Torus	13 in (0.015 in thickness)
Diameter of Struts	7 in (0.015 in thickness)
Moment of Inertia of three struts	2.02 in^4
Moment of Inertia of torus	12.8 in^4
Polar Moment of Inertia of struts	4.04 in^4
Polar Moment of Inertia of torus	25.6 in^4

A displacement analysis was done using NASTRAN Program. The model was excited with four types of loads. They are

1) Internal pressure of 10^{-5} psi of reflector/canopy chamber.

2) Gravity load due to 0.002g in X direction.

3) Gravity load due to 0.002g in Y direction.

4) Gravity load due to 0.002g in Z direction.

Also the model was analyzed due to a combination of internal pressure plus one of the gravity loads. The figures 4 through 7 depict the zoomed deflected shape of the reflector. It should be noted that the struts, torus and canopy are shown in its undeformed position.

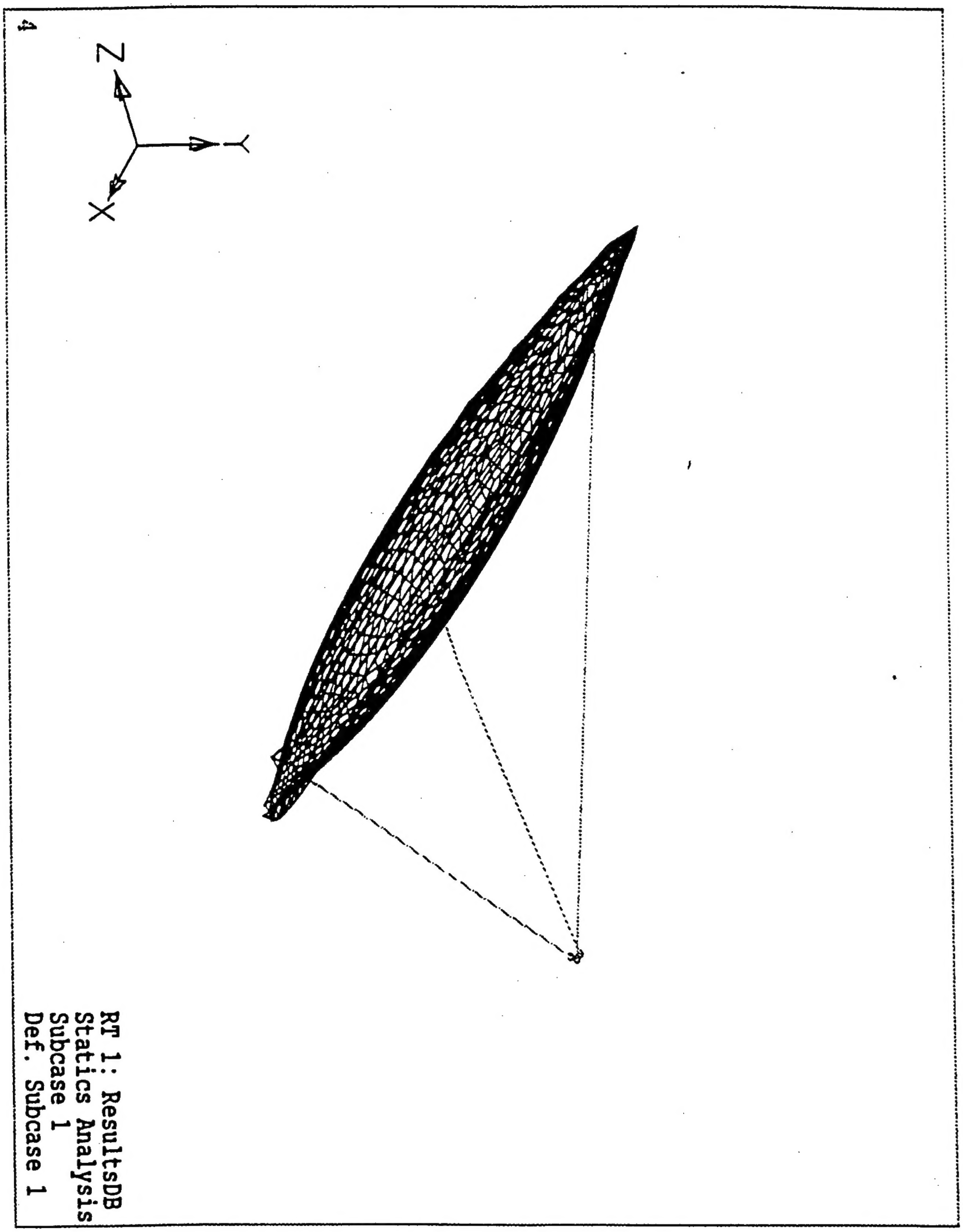

Figure 4: Deflected shape of the reflector due to internal pressure of the chamber

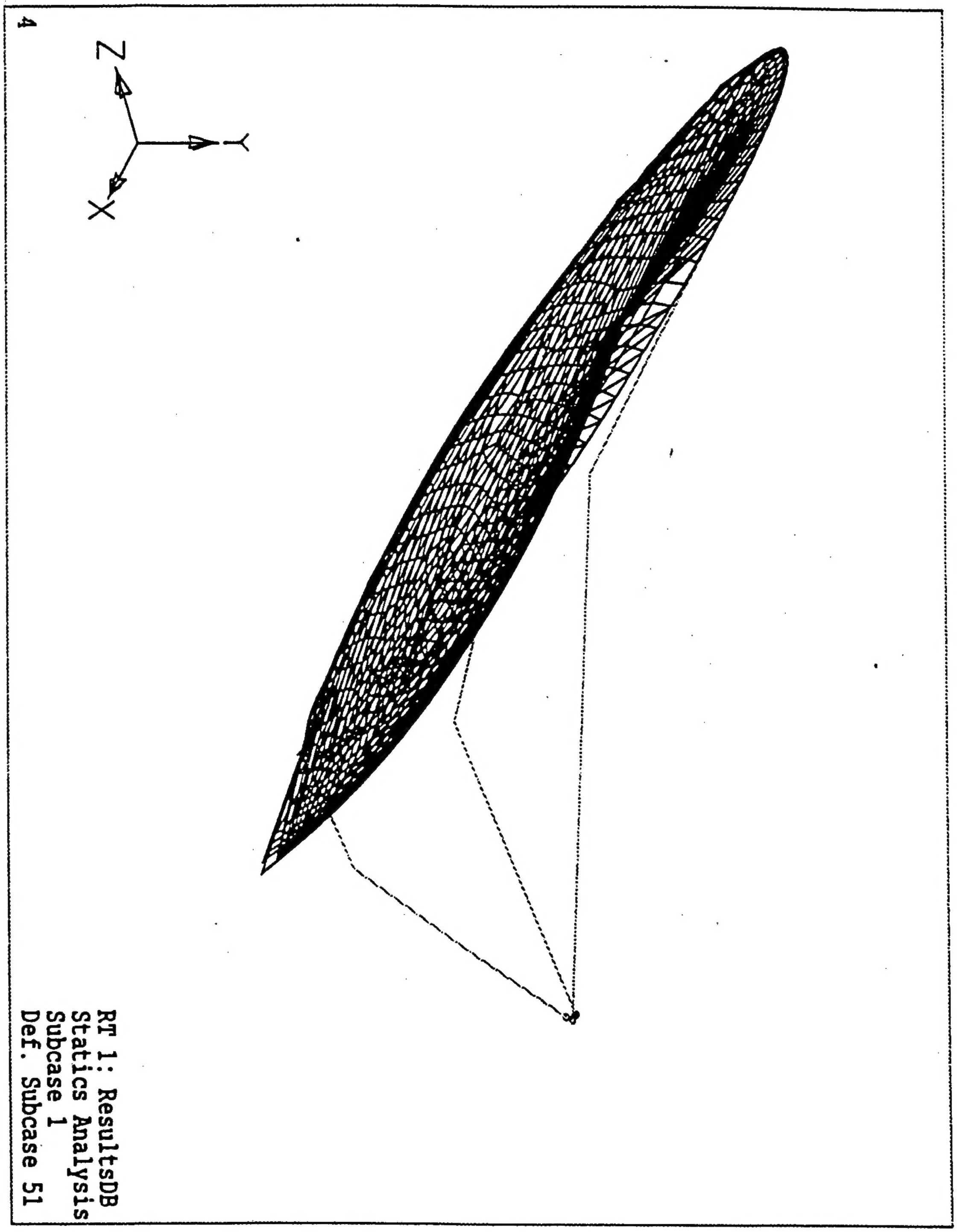

Figure 5: Deflected shape of the reflector due to internal pressure plus acceleration in X direction.

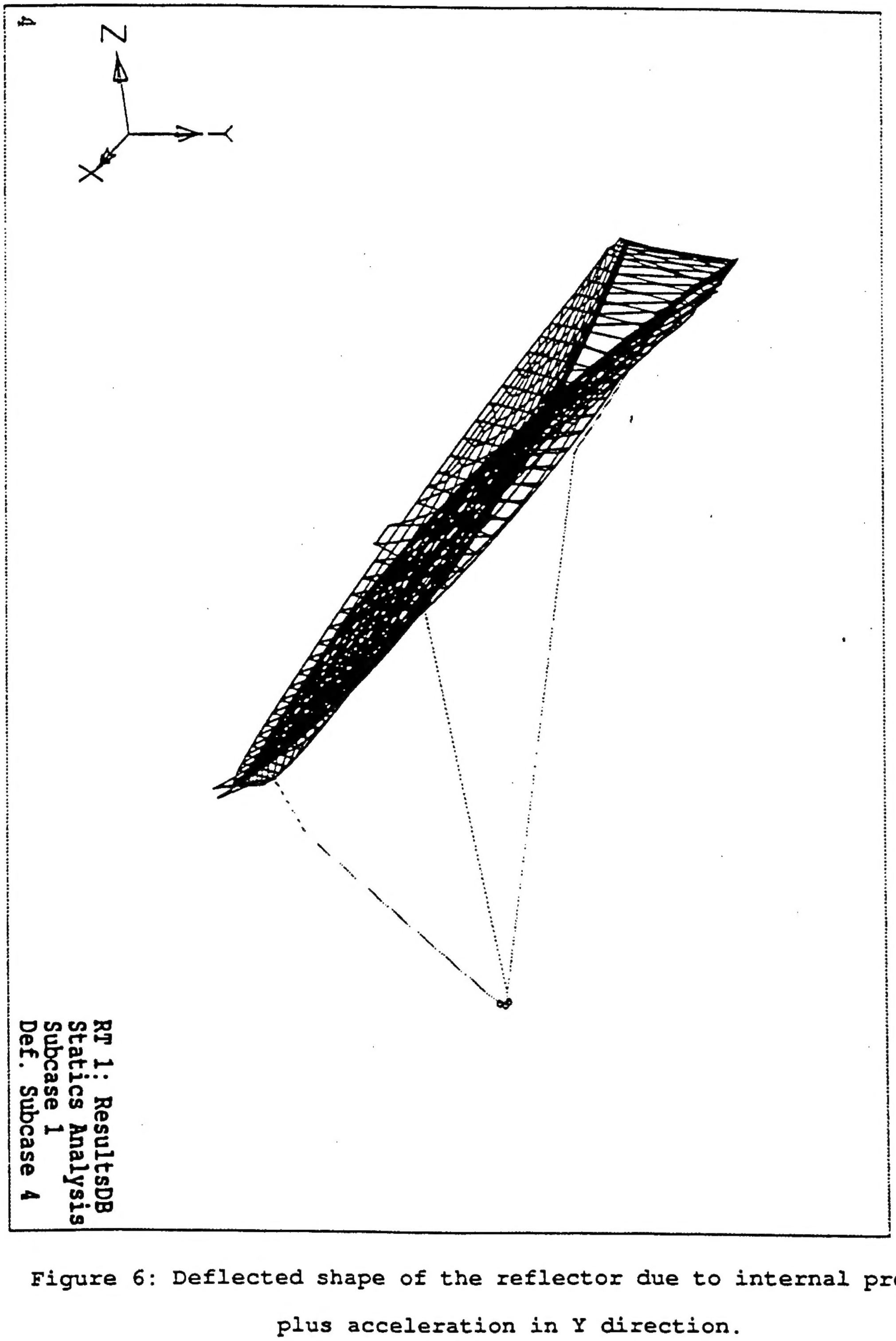

Figure 6: Deflected shape of the reflector due to internal pressure plus acceleration in Y direction.

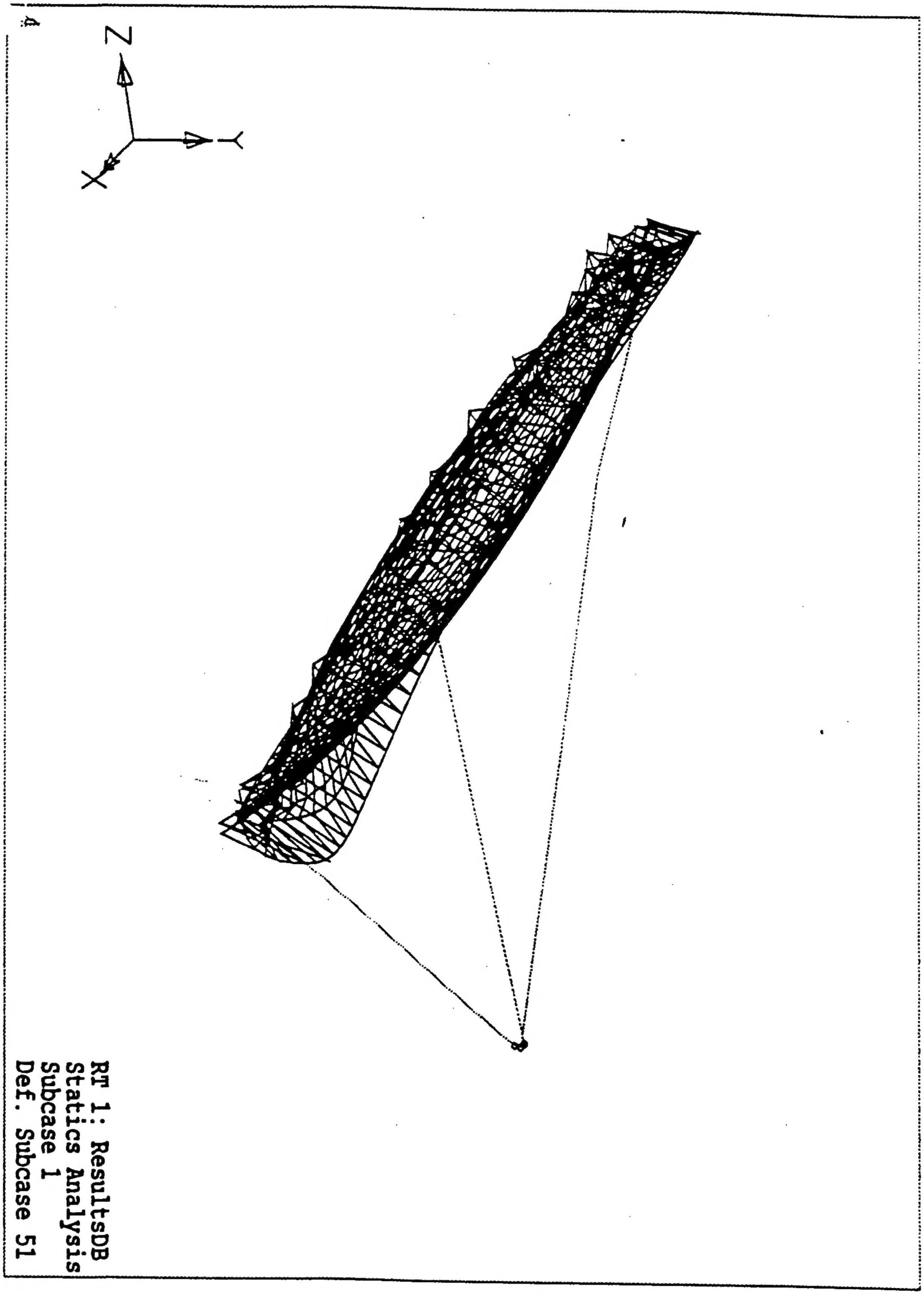

Figure 7: Deflected shape of the reflector due to internal pressure plus acceleration in Z direction.

ANALYSIS RESULTS

The displacements of the end of the three struts are shown in Table 2, for gravity loads in each direction. They are less than 6 inches.

The displacement of the focal point is calculated as follows:

i) Displacement with reference to the spacial displacement of the torus.
ii) Twice displacement with reference to rotation of the torus.

This is because the torus/reflector will cause light rays to be reflected at twice the angle of torus rotation.

Table 2 Displacements at the end of three struts: (inches)

	X displacement	Y displacement	Z displacement
Acceleration in X direction and internal pressure			
Strut 1	-4.7121	-0.5237	-1.9067
Strut 2	-4.7363	0.6694	1.8945
Strut 3	-1.0651	0.0103	0.01057
Acceleration in Y direction and internal pressure			
Strut 1	0.0446	-3.5623	0.5601
Strut 2	0.0206	-3.4828	0.5252
Strut 3	0.0424	-1.3598	-1.3943
Acceleration in Z direction and internal pressure			
Strut 1	0.0451	0.04649	0.0118
Strut 2	0.02174	0.1282	0.0289
Strut 3	0.04355	0.01517	0.0155

The Figure 4 shows the deflected shape of the reflector due to the internal pressure of the reflector/canopy chamber. The non uniform shape of displacements are apparent especially at two ends. The figure 5 depicts the deflected shape when the inflated chamber and the structural system is subjected to 0.002g acceleration in X direction. The potato chipping effect due to non uniform deflection is quite apparent in this diagram. The same effect due to the inflation pressure and a 0.002g acceleration in the Y direction is shown in

Figure 6. Similarly, the Figure 7 depicts the same effect due to acceleration in the Z direction. It should be emphasized that these figures show only the deflected shape of the reflector. The canopy and the struts are shown at their undeformed positions. In many of these plots the struts appear to have had sudden deflection near the reflector. This is just to facilitate graphic view of the deflections at the reflector.

DISCUSSION OF RESULTS

The listed Tables 2 and 3 document the X, Y, and Z components of the displacements of the end of three support struts. All of them are less than 6 inches, which confirms small displacements of the struts. The Table 3 documents focal point displacements. The current study results were obtained by running another independent Nastran run of 3 simple struts from the end of the support struts to the focal point. The three struts end at three dummy node points at the focal point. One end of each of the struts were subjected to displacements and twice rotations obtained from the previous runs for the whole model. The displacements at the three dummy nodes are, the focal point displacements with reference to the three ends of the struts. A simple average values are documented in the Table 3, for acceleration in the X and Y directions. They are less than six inches. However, it should be emphasized that these results are for the type of materials and strut system selected. The structure can be made stiffer by replacing the three main struts with a six strut system or a built up truss system. The results are compared with the Reference (7) model for the same problem. In the Reference (7) model the ends of the three struts are connected to a non structural frame (i.e. with low EI values), which connects these three points to a triangular frame. A strut is run from the mid point of one of the struts to the focal point via center of gravity of the torus. Hence, the focal point displacement is the weighted average of the displacements of end of three struts. The comparison in Table 3 shows agreement of results of current

Table 3 Displacement of focal point: Results Comparsion (inches)

Current Study Results	X displacement	Y displacement	Z displacement
Acceleration in X direction	-4.13	0.17	0.02
Acceleration in Y direction	-0.63	2.88	-0.569

Reference 7 Results	X displacement	Y displacement	Z displacement
Acceleration in X direction	-2.35	0.0	0.0
Acceleration in Y direction	0	2.10	-0.32

SUMMARY

This report documents the possibility of diffusion of the focal point on solar concentrators due to thrust loads. Also the non uniform deformation of the

The present study documents potato chipping effect of the reflector, due to the interaction of the torus/reflector chamber. Use of a secondary concentrator system with a single chamber reflector may alleviate this problem. A pointing and accuracy analysis of a single chamber reflector is needed to study the suitability of this concept.

ACKNOWLEDGEMENT

Financial support through the Research and Development Laboratory of AFOSR is appreciated. Thanks are due to M. Holmes, S. Cartier, Capt. D. Castillo, N. Abayakaran, and S. Lou for their help during this study.